VAPOR LOCKING AND HEAT TRANSFER OF MULTIPLE LAYERS

MASTER

by

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Summary

This work was undertaken to study the vapor formation and heat transfer of multiple layers under both steady state and transient conditions. The change in capacitance between the two sides of the heated channel is measured to determine the volume fraction of the vapor in the cooling channel. It is found that the heat transfer characteristics depend on the vapor accumulation and the velocity of vapor flow. The vapor locking heat flux is decreased when the vapor accumulation is increased.

Introduction

The cryogenic stability of a superconducting magnet depends on the heat transfer characteristics of the liquid helium cooling channels. One of the factors which affects the heat transfer to the channel is the amount of vapor accumulated in the channel. It is especially important to design a large magnet with cooling channels large enough to ensure the recovery of a normal zone produced in the magnet following the mechanical disturbances.

The study of the vapor formations and the heat transfer characteristics of the helium cooling channel has been studied by various investigators. The vapor formation and heat transfer of a simulated cryostable superconductor in single layer structure has been reported previously. In this paper, the results of multiple layers are reported. It is the purpose of this study to investigate the heat transfer characteristics of liquid helium channels in the multiple layers. We are especially interested in the effects on heat transfer characteristics of vapor accumulation and of the vapor flow in the channel during a heat pulse or a steady state heat load.

Heat flux, energy density, temperature rise, and vapor fraction, are defined as heater power to cooling surface, heater energy to conductor, temperature difference between the sample and the liquid helium bath, and the volume fraction of vapor in the cooling channel, respectively. The values presented under transient conditions are the maximum amplitude observed for each pulse.

Apparatus and Measuring Techniques

The samples are made to simulate the real cryostable superconductor and the cooling channels to be used in the large MHD superconducting magnet, designated as CFFF-3CMS, currently under construction at Argonne National Laboratory (ANL). The cross section of the conductor is 3.1 by 0.47 cm, and that of the cooling channel is 0.47 by 0.076 cm. Three conductors are sandwiched between insulation of 0.064-cm-thick pultruded fiberglass strip. A 0.0064-cm-thick double-coated adhesive Mylar tape was used to bond the conductor together. The resulting assembly provided actual cooling channels. Between two assembly stages are the 0.71-cm-thick by 1.53-cm-width Micarta strips with 1.21-cm-space to simulate the identical cooling conditions of the conductors within the

CFFF-3CMS coil structures. Figure 1 shows the triple-layer stage for measuring the heat transfer characteristics and vapor locking. Figure 2 shows the fourteen-layer stage for measuring vapor propagations.

A 0.0025-cm-thick stainless steel heater was inserted in the middle conductor. The insulation between the heater and the conductor was a 0.0075-cm-thick lens paper impregnated with GE-7031 insulating varnish. Maximum power dissipated by the heater was about 5 kW.

Fig. 1 Triple-Layers Stage for Measuring the Heat Transfer and Vapor Locking

Fig. 2 Assembly of simulated single coil layer for vapor-locking and heat transfer experiments. A: simulated conductor with heater; B: simulated conductor without heater; C: pultruded fiberglass insulation and front-cooling channel; D: pultruded fiberglass insulation and rear cooling channel; E: Micarta blocks; F: half-covering Micarta blocks; G: copper holders; H: horizontal cooling channel; and I: vertical cooling channel.

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Fig. 3A Capacitance Bridge to Measure the Vapor Fraction.

Fig. 3B Calibration Curve

The temperature of the conductors was measured with a Chromel vs. gold-0.07 at .% iron thermocouple. Good thermal coupling of the thermocouple insulation was achieved by wrapping the thermocouple with a single layer of 0.0025-cm-thick lens paper impregnated with GE-7031 varnish.

The vapor fractions in the cooling channels were determined by measuring the change in capacitance of the channel. A capacitance bridge with a triaxial cable to compensate for any leakage current is used. The electronic circuitry of this capacitance bridge is shown in Fig. 3A. Before measurement, some of the known capacitors are used to calibrate the capacitance-voltage characteristics. Capacitor C_1 and potentiometer VR_1 are used for balance adjustment, while potentiometer VR_2 is used for leakage current compensation, and potentiometer VR_3 for output amplitude adjustment. One typical calibration curve of the bridge is shown in Fig. 3B. The maximum capacitance change for the cooling channel of the simulated layers was about 2.1 pF. The wetted area of the front side of the heated conductor was 36.09 cm², and that of the rear side was 17.84 cm². The volume of the conductor used was 28.53 cm³ while the volume of each channel was 2.86 cm³.

Results

1. Heat Transfer Characteristics

The steady state electrical power is applied to the heaters of the triple-layer stage. Figure 4A shows the heat flux vs. temperature rise when only

the upper layer was heated, while Fig. 4B shows upper and central layers were heated simultaneously with the same electrical power. Figure 4C shows the heat transfer characteristics when three layers were heated simultaneously with equivalent power. The temperature rise presented is the temperature difference between the upper layer and the liquid helium bath. The critical burnout heat flux for the transition from nucleate boiling to film boiling are about 0.40, 0.381, 0.371 w/cm² for single, double, and triple heating, respectively. The recovery heat flux for transition from film boiling to nucleate boiling are 0.244, 0.25, 0.257 w/cm², respectively. When the steady state heat flux is greater than the critical burnout heat flux, the temperature increases markedly to above 7 K. The cooling channel becomes vapor locking. From Fig. 4, one found that the vapor accumulation in the channel will decrease the value of critical heat flux for a runaway transition, but the vapor flow through the channel improves the recovery transition.

To investigate the effects of the vapor accumulation and the vapor flow on the heat transfer characteristics, a constant-biasing heat flux is applied to the lower layer. This generates a constant vapor flow through the upper layers. Figure 5 shows the heat transfer characteristics for the constant biasing heat flux are 0.07, 0.75 w/cm², respectively, which provide vapor fractions of 0.099, 0.27 in the front channel, and 0.128, 0.307 in the rear channel. In Fig. 5A, the critical burnout heat flux is 0.39 w/cm², and that of Fig. 5B is 0.35 w/cm². The recovery heat flux are 0.27, 0.255 w/cm², respectively.

Fig. 4 Steady State Heat Transfer Characteristics Under Different Heating Conditions

Fig. 5 Steady State Heat Transfer Characteristics Under Different Biasing Vapor-Flow Conditions

Compared with Fig. 5, one found that the vapor flow improves the heat transfer characteristics. However, the vapor accumulation represses it.

Figure 6 shows the heat transfer characteristics under single, double, and triple heating conditions. It is indicated that the temperature rise is a function of the energy density and the vapor accumulation, and it is independent of the pulse duration.

Fig. 6 Transient Heat Transfer Characteristics Under Different Heating Conditions

2. Vapor Formation and Vapor Accumulation

Figure 7 shows the vapor fraction of the upper layer for different heating conditions. For instance, if the heat flux is 0.2 w/cm^2 , the vapor fractions of front channels are 0.43 for single heating and 0.57 for triple heating, and vapor fractions of rear channels are 0.50, and 0.64, respectively. The accumulated vapor fractions, which is supplied by the lower two layers, is about 7% for the front and for the rear channel.

Fig. 7 Steady State Vapor Formation Under Different Heating Conditions

The vapor propagations from the first layer at bottom position to the 14th layer at top, are shown in Figs. 8 and 9. The heating power is applied to the first layer only. Figure 8 is under steady state condition. Almost half the amount of vapors are propagated from the first layer to the second layer. Also note that the vapor propagation in the front channel is better than that in the rear channel. This is because the wetted surface of the front side is continuous from bottom to top, while the wetted surface of the rear side is blocked by turn-to-turn insulation. This obstruction inhibits the free convection in the rear channel.

The vapor propagation under transient conditions are shown in Fig. 9. The peak vapor fraction of the cooling channel is about half the value of that in the underneath channel. This result is consistent with the results in Fig. 8.

Conclusions

Based on the experimental results obtained the following conclusions can be made.

1. The vapor accumulations in the multiple layers repress the heat transfer characteristics. On the contrary, the vapor flow in the multiple layers improves the heat transfer. The optimum conditions will

depend on the vapor propagation path and the velocity of vapor flow.

2. The critical burnout heat flux in the multiple layers is worse than that in a single layer. However, the recovery heat flux in multiple layers is better than that in a single layer.

3. About half the amount of vapors propagate into the upright channels, while the rest propagate sideways to the liquid helium bath.

Fig. 8 Vapor Propagation Under Steady State Conditions

Fig. 9 Vapor Propagation Under Transient Conditions

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